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Design Of A Low-Impact Wastewater Collection And Treatment System For Siladen Island In Indonesia

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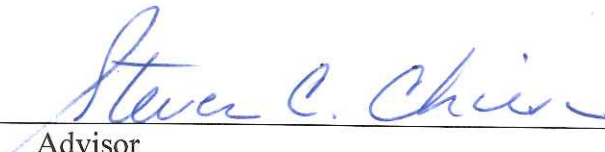
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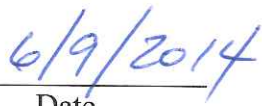
DESIGN OF A LOW-IMPACT WASTEWATER COLLECTION AND TREATMENT
SYSTEM FOR SILADEN ISLAND IN INDONESIA

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BACHELOR OF SCIENCE IN CIVIL ENGINEERING




Advisor



Date



Chairman of Department



Date

DESIGN OF A LOW-IMPACT WASTEWATER COLLECTION AND TREATMENT
SYSTEM FOR SILADEN ISLAND IN INDONESIA

by

Kyle Astill
Charles Rymer
&
Joseph Sarmiento

SENIOR DESIGN PROJECT REPORT

submitted to
the Department of Civil Engineering

of

SANTA CLARA UNIVERSITY

in partial fulfillment of the requirements
for the degree of
Bachelor of Science in Civil Engineering

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Spring 2014

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DESIGN OF A LOW-IMPACT WASTEWATER COLLECTION AND TREATMENT SYSTEM FOR SILADEN ISLAND IN INDONESIA

Kyle Astill, Charles Rymer, and Joseph Sarmiento

Department of Civil Engineering
Santa Clara University, Spring 2014

ABSTRACT

Untreated wastewater is highly destructive to human health and the environment. Choosing an island location, Pulau Siladen, which has no wastewater treatment solution, the design team embarked upon designing a centralized collection and treatment system to treat the island population's wastewater, in the interests of preserving human health and the sensitive coral reefs surrounding the island. This system features a gravity sewer system, flow equalization, sequencing batch reactor, sand filter and disinfection as part of the treatment process. This project will emphasize the reduction in use of highly specialized and manufactured components, in an effort to minimize the economic, environmental and societal impacts of implementing this project. Due to the large scale of this project, it is estimated that 1 more year of work by a senior design project team will be necessary to see this design in a state ready to be implemented on the island.

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INTRODUCTION

Proper sanitation is a basic human need. “It is a crucial stepping stone to better health,” and vital in ensuring a decent quality of living and preventing poverty. (UNICEF) “2.5 billion people still lack access to improved sanitation, including 1.2 billion who have no facilities at all... 1.5 million children die a year, succumbing to diarrheal diseases... The message is clear: We need to greatly accelerate progress in sanitation, particularly in sub-Saharan Africa and Southern Asia.” (UNICEF) Data shows that “people are choosing to move up the ‘sanitation ladder’, abandoning open defecation and revealing a demand for sanitation facilities,” (UNICEF) illuminating a reason for this project’s conception and completion.



Figure 1: Slum conditions result from poor sanitation.

Human health is not the only thing adversely affected by untreated wastewater. Beautiful coral reefs are a natural gem in our oceans and “are home to a quarter of all marine fish species and provide food, coastal protection, and livelihood to 500 million people.”(Whelpton) There is nothing quite like a pristine reef, and they are non-renewable and critically endangered.

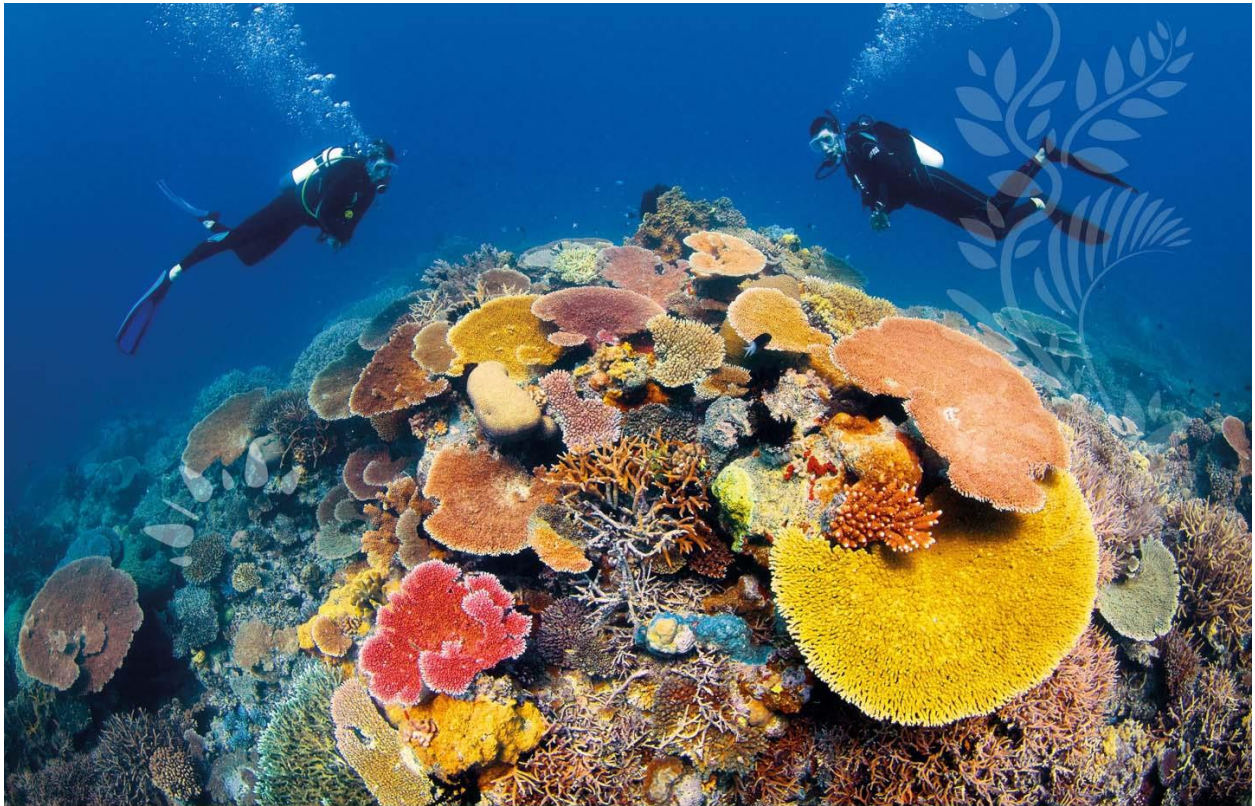


Figure 2: Vibrant coral reefs are beautiful yet endangered.

Coral bleaching is a term used widely when describing the destruction of the world's reefs by artificial influences like pollution. A University of Georgia study found that a human pathogen responsible for white pox, can pass into a coral ecosystem through untreated human wastewater and become a coral pathogen, causing bleaching and internal destruction of coral species. (Whelpton) Furthermore, the nutrient rich wastewater often causes eutrophication, where algal bloom occurs, affecting oxygen levels and disrupting the natural cycle of reefs.



Figure 3: Disease wreaks havoc on coral ecosystems.

With the goal of preserving natural coral reef ecosystems and providing proper sanitation to people deprived of this basic service, the design team proceeded to design and develop a low impact and practical way to provide said sanitation, that can be constructed for any community in need of this service. This treatment system would have to be centralized and able to collect an entire community's wastewater, and then treat it to the relevant wastewater discharge standards.

The system would have to be first developed to fully provide sanitation for a single location, as a form of testing for treatment effectiveness of the system. If successful, this system would be scaled and adapted to suit other communities similar to the initial site location. This initial system would have to be scalable and suitable for a small community, as it is desired to provide proper sanitation to people far and wide, not just those who happen to be living in larger cities where a municipal type treatment system is most suitable. Because economic power and education between first world and third world countries is disparate, this system would have to have a minimal economic and environment footprint, as well as being easily operable and maintained by unskilled laborers.

SITE LOCATION

Coral Reefs

The world's richest coral reefs are scattered far and few between amongst few locations, including Australia, The Mediterranean oceans, many islands in the Pacific and Atlantic oceans, and all of the countries sharing the Southeast Asia sea. Amongst Scuba diving tourists/professionals, and those in the industry of marine resources conservation, the world's most beautiful but also most endangered reefs are situated in Indonesia. A report by Worldwatch Institute, a large environmental research organization that works closely with the United States Government's policymakers stated:

“If you're going to talk about coral, Indonesia is the place to be. With the world's richest and most extensive coral reefs, Indonesia probably harbors more underwater species than any other nation. This archipelago of 17,000 islands is also where the stakes are highest for ocean conservation: more people live closer to reefs here, in the fourth-most populous nation on Earth, than anywhere else... The devastating implications of El Niño and climate change for corals, and ways to stop reef-killing fishing practices and the spread of coral disease-are tremendously important for this nation of coastal dwellers and fish eaters.” (Worldwatch)



Figure 4: Rich coral reef ecosystems in Indonesia.

Considering that Indonesia, the 4th most populous country, is a developing nation with many of its citizens living in poverty, the design team focused its interest in designing a system for this country. “In 1999 as much as 47.97 million people were classified as impoverished, representing 23.43% of the nation's population” (Indonesian Business, 117), however strides have been made and now the percentage of nation’s population has “fell to 16.6% as of march 2007...representing 39.3 million people.” (Indonesian Business, 117)

It is further stated in this report that since most Indonesians live in densely populated cities, and with the greater economic prosperity being experienced in the capital, Jakarta. However, since the cities’ improvements to infrastructure, the poverty decrease reported does not account for the disparity in living conditions for urbanized citizens and for rural citizens living in fishing villages on many of the 17,000 islands mentioned earlier. These are the people living in poverty, and lacking basic sanitation. However for the fortunate residents of the pristine barrier

reef islands, the locals are assisted above the poverty line by the money offered by tourism from the thousands of Scuba diving enthusiasts eager to experience some of the world's most beautiful marine wildlife.

One such island, that became the one selected for the design team's project is Siladen Island (Pulau Siladen), "one of five islands in Bunaken National Park, Manado. The island is just eight miles from the center of Manado (the capital city of the North Sulawesi province of Indonesia) and can be reached by motor boat about 45 minutes. (Indoasia Traveling)



Figure 5: Pulau Siladen surrounded by barrier reef. Resorts located on west coast and local village to the south.

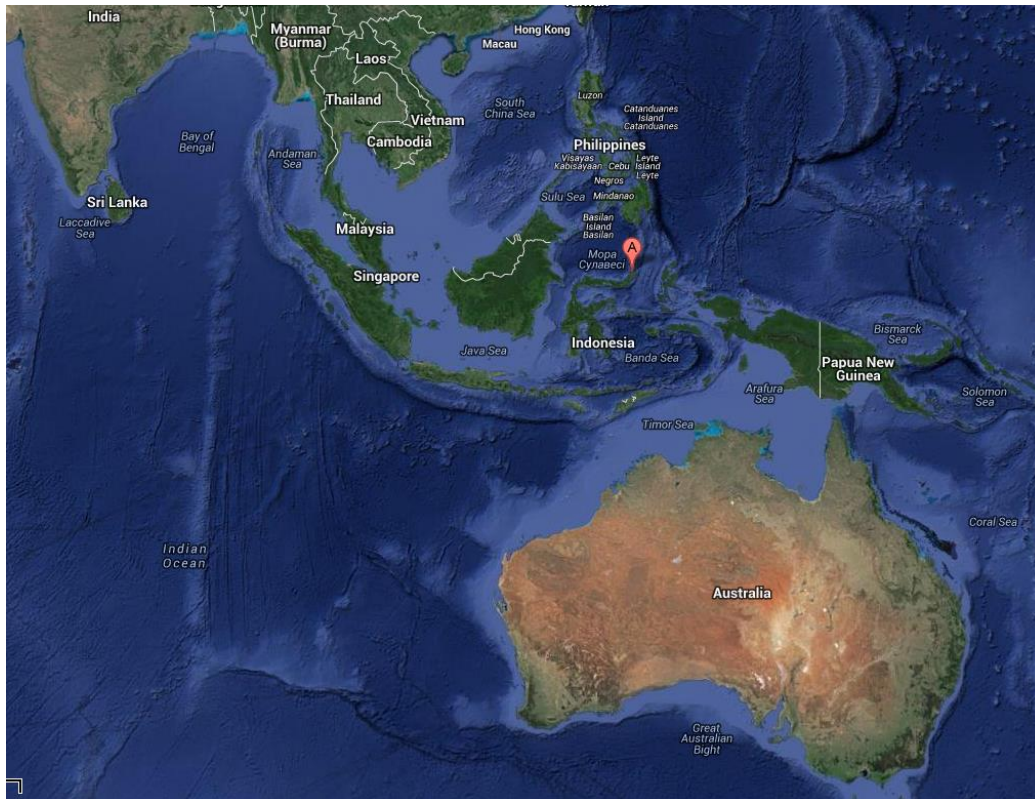


Figure 6: Siladen Island (A) with respect to the Southeast Asia region

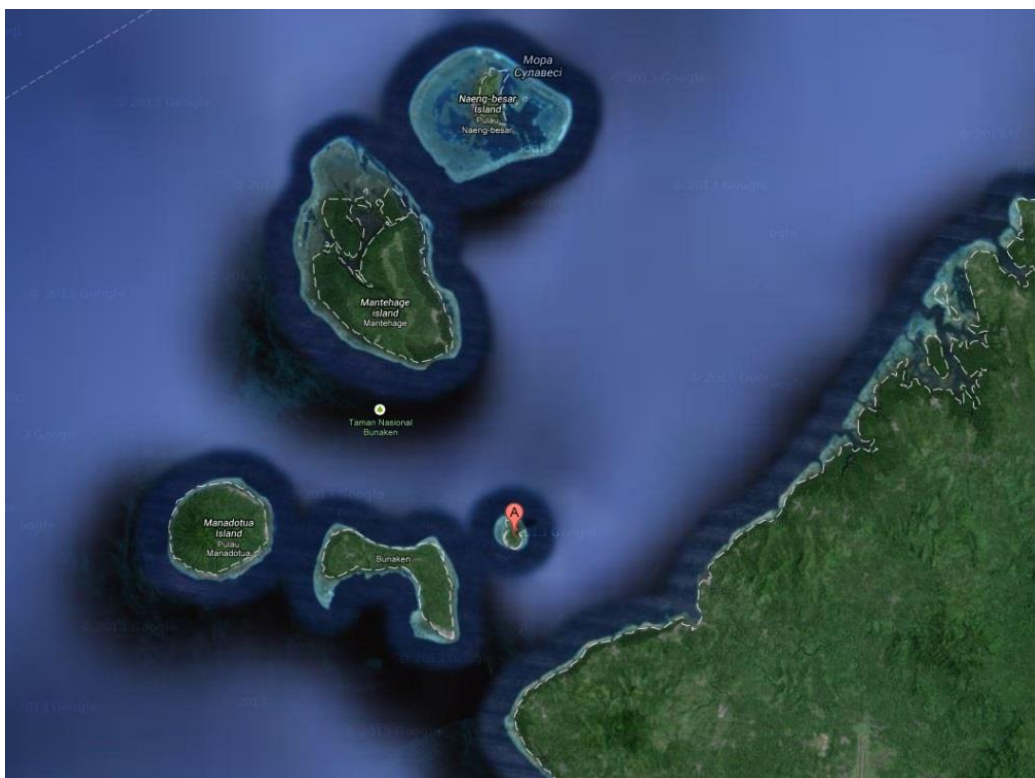


Figure 7: Pulau Siladen (A) and other similar Manado Islands.

Pulau Siladen

Pulau Siladen is a tiny island, approximately 2000ft wide and 3000ft tall, home to 350 inhabitants and thousands of environmentally sensitive coral reef and fish species. About 200 people are locals, living in basic villages to the south of the island and approximately 150 people on the island are resort staff or guests of the 5 Scuba diving resorts operating on the west coast of the island, where the barrier reef is most abundant.



Figure 8: Panorama of the island.



Figure 9: One resort, view from water.

The design team has been in contact with a dive resort owner and operator on Pulau Siladen since before embarking on this project. The island has very minimal documentation, making it difficult to obtain solid criteria for the design team to consider. In order to obtain

sufficient data for the system design, the design team to relied on specific and quality questions and answers with the island contact, as well as using Google earth and manipulating data with various engineering programs at the team's disposal.

The level of quality of construction varies on the island, with some locals living in shanty-like houses, and others with basic concrete construction.



Figure 10: Higher quality concrete construction for some locals. Main road is a footpath as there are no vehicles on the island.

While the infrastructure is limited, quality construction is achieved and a reasonable quality of living is provided to resort guests. As per the island contact's information, reliable electrical power is provided by diesel generators which feed each resort with sufficient energy for their operation including the use of laundry machines and air conditioner units for guest rooms as well as water heating and other process equipment.



Figure 11: Resort restaurant building retains traditional Indonesian architecture while being of adequate construction on a concrete slab.



Figure 12: One resort is capable of maintaining a luxurious pool.



Figure 13: Crystal clear waters off the northern point.



Figure 14: Beautiful reef formations and water, worthy of protection.

It is clear that there is much to be valued on Pulau Siladen. Resort owners have invested much in infrastructure, to build and operate such quality resorts in this pristine remote island. There is much at stake for the resort operators economically, for if this island's corals reefs are severely degraded, or human health is known to be at risk on this island, resort operators and locals alike would no longer reap the benefits of the steady income from tourism here, hence it is all parties' best interests to protect and preserve Pulau Siladen. However, for all the beauty and investment in infrastructure on the island, there is still currently no method of providing proper sanitation whatsoever on the island.

According to the island contact, currently in place are individual small septic pits situated under each lavatory. This is a primitive ancient Dutch method where layers of dirt, coral and natural fibers filter the effluent produced by each toilet, collecting the sludge in the membranes and the mildly filtered water passes below, permeating into the soil. With this method, the excreta is not distanced sufficiently from humans and manual labor is required to scrape the toxic sludge from the membranes. Due to the poor level of treatment and the residual sludge remaining in the ground, this does not classify as an adequate and sustainable practice for providing proper sanitation. This potentially leaves the local environment susceptible to damage caused by wastewater contamination.

In an effort to be sustainable, some resort operators state on their websites that kitchen sink/food preparation water is collected and transported by boat to be dumped into the ocean. (Siladen) Considering that this design team's Wastewater Treatment (WWT) system will treat all forms of wastewater, this laborious collection and discharge method will be eliminated, helping offset the cost in the implementation of the designed system.

It is reported that resort owners are concerned about the purity of the groundwater and possible sludge runoff issues due to prolonged use of an inadequate treatment method. It is also reported that fresh water is scarce and that all island inhabitants, including guests are encouraged to use fresh water very sparingly. Rainwater and groundwater are the two sources of potable water. It would be catastrophic if the aquifer became contaminated, forcing wells to be decommissioned, and requiring the difficult task of decontaminating it.

According to World Weather Online, this region is susceptible to heavy storm downpour due to its tropical climate. (WWO) This large volume of rainfall causes runoff into the ocean to be a regular occurrence. With the soil being laden with effluent, paired with large amounts of runoff, it is inevitable that contaminants will make it into the ocean, and the contaminated soil would certainly affect land based life in the long run.

The Siladen resort on the island has a mission “to preserve the natural habitat and assist the local villagers.”(Siladen) It is the design team’s goal in assisting island inhabitants in fulfilling this mission, therefore validating this project as having community need, and additionally satisfying a commercial need, by preserving the assets that generate economic prosperity on the island. Primarily, the goal is to preserve the natural habitat and safeguard human health with a long term, cost effective and sustainable waste solution. It would be a wise investment for the primary stakeholders on the island.

DESIGN PHILOSOPHY

Potential Solutions

During the design process, four potential solutions to providing Wastewater Treatment for Pulau Siladen were identified.

Septic tank

The first solution was the implementation of a traditional septic tank system, a proper implementation of the system to serve long term needs. Traditional septic tank systems use a leach field which makes water permeate into the ground. These leach fields however, require a large amount of land for adequate sludge removal and must not be situated above an unconfined aquifer with shallow water table, which is a primary source of potable water for the islanders. Pulau Siladen has little area to build a leach field and according to the island contact, the water table is approx. 15ft deep, raising concern for the potential contamination of this water resource.

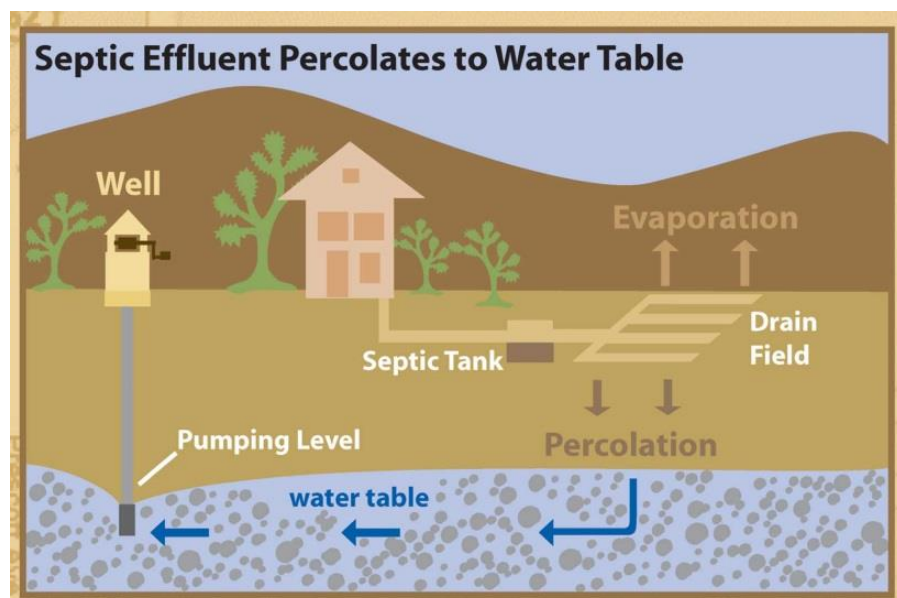


Figure 15: Conceptual Drawing of a Traditional Septic Tank System.

Municipal-type wastewater treatment plant

The second and most prevalent potential solution identified for providing WWT is a municipal-type wastewater treatment plant. These are most common in many American cities. The facility itself requires a large area and serves a large population for it to be cost effective, and are often designed to treat millions of gallons of effluent a day. Siladen is expected to produce a very small flow of effluent due to the small island and population size, ruling this out. Additionally, Manado, the largest city in the region does not even use a traditional WWTP, instead using large septic tank systems, afforded by the vast area of open land compared to neighboring islands and population size.



Figure 16: Municipal-Type Wastewater Treatment Facility.

Holding tank and collection

The third potential solution was to implement a collection system and holding tank on the island. The wastewater would be collected by all wastewater producing fixtures and held in a tank, where the wastewater would subsequently be hauled by boat off the island for proper treatment at a regional WWTP. However in all practicality considering the level of infrastructure and common practices in Indonesia, the waste would be dumped into the sea, needless to say, the

design team did not accept this. Further detraction from this alternative is that this process would require laborious trips to and from the island, burning fuel which is only getting more expensive.

Package treatment plant

The last considered alternative was the use of a package-type treatment plant. Package-type treatment plants are similar to and often substituted for some municipal-type plants. They are delivered in 1 unit requiring only to hook the unit up to pipes and power, they're also modular and scalable for different type of loads, making them ideal for many ranges of lower flows. This would be the ideal product to use to provide quality sanitation to Pulau Siladen, however they are very expensive to purchase, and the large unit must be shipped across oceans and delivered onto the island, even though there is no solid pier to dock a cargo hauling vessel to.



Figure 17: Common package treatment plant layout.

Logic in Selecting a Solution

There were two primary overall considerations taken when determining the best solution to Pulau Siladen's wastewater problem: site constraints and economic considerations. For the site, the solution had to be practical and appropriate for a small island population. Many traditional solutions are better suited for larger populations, so it is imperative that there is a solution that is adaptable for Pulau Siladen's population. The island is remote and difficult to deliver cargo to unless it can be hauled from a small basic boat on the beach, ruling out the use of large, heavy or bulky components. There is a mechanical engineer at at least one resort who can fix machines and systems which is useful for routine maintenance and oversight of the system with training.

For economic considerations, Indonesia has drastically lower labor costs than America; their minimum wage ranges from \$0.50 to \$1.25/hour in American dollars. (Wage Indicator) That is something the design team considered in its opinion of most probable cost. Shipping costs were considered in the design because most parts would be produced in America and shipped over to Indonesia. Operation and maintenance of the system was considered. When determining the system components, it was imperative to make sure maintenance of the system was ergonomic. Otherwise the system would be short-lived and would fail. The system was designed to use readily-available and redundant parts, such as spare pumps, primarily for those not as readily-available. This would ensure that if those parts fail, they can be replaced and the system can continue operating without having to wait for replacements or custom parts to be shipped.

Chosen Solution Strategy

After considering the potential solutions to the problems previously mentioned, the most suitable option was the package-type treatment approach. This system incorporates a gravity sewer collection system, Sequencing Batch Reactor (SBR) with slow-trickle intermittent sand filters and finally a disinfection system to remove pathogens before discharge into the reef water. Treated water pipe will have a valve fitting to divert flow to a chlorine contact chamber to provide residual disinfection, allowing the treated water to be used as recycled water to offset potable water demands.

Various methods for providing biological treatment were considered, an SBR was selected as the most suitable option and the design team determined that only 1 SBR tank would be required, lending itself merit due to the small land footprint stipulation. The fact that “equalization, aeration and sedimentation occurs in time sequence batches rather than in the conventional space sequence of continuous-flow systems”, (Abreu & Estrada) as well as all processes occurring in just 1 tank further reinforced the decision to incorporate an SBR design. For such a small community and isolated location with several limitations, this type of system is the best option. This entire system offers a relatively simple, small-scale solution that is ideal for the low island population. It is designed to have minimal process control and be easily operated and maintained by the locals who lack technical expertise.

There are specific constraints that must be considered and designed for. First, the effluent from the system must be treated to a stringent degree so that it can be safely discharged into the ocean without harming people or the environment. The system should use readily available parts with common materials. This will prevent any major issues when replacing parts or finding spares, should failure occur. One major objective is to minimize the initial and life-cycle cost, so

finding cost effective components and materials that are not overpowered or designed, will play a significant role in the success of this system. Also, due to the location and remoteness of the island, delivering necessary items is an added burden. Minimizing trips to and from the island for supplies will save time and money in completing this project. In case of any failure or damage to parts, ideally enough redundant materials are on site so that any problems may be addressed immediately. Ordering spare parts may be a lengthy process given the island's location. Having redundant materials on hand gives the locals the peace of mind that if issues arise, they may be resolved in a timely fashion.

Project Design Tasks

The project design tasks can be split into two separate categories. The first set of tasks involves the collection of sufficient data to begin designing. These tasks include researching environmental discharge standards, determining the average daily wastewater flow on the island, understanding island topography, and calculating the peak flow for equalization purposes. Knowledge of the island topography and geographical constraints are required to layout and design the sewer network and collection system to gather waste from all fixtures effectively. The second category of the project tasks consist of the actual design of all the treatment system components. Once the daily flow and peak flow were determined, the equalization sump could be designed, along with the accompanying piping and components.

The second major system component is the SBR. The design of this involved the design of the basin itself, including tank sizing and geometry, as well as construction method and material selection. Equipment to provide the biological treatment has to be considered, specifically designing a method and component to adequately mix, aerate and decant the water. Further considerations for the SBR design were in devising a timing schedule for each phase of treatment, so that timely treatment could occur each day without requiring multiple SBR tanks.

The slow trickle sand filters are the following component in the treatment process which required design and research. The size, orientation and materials are essential to its operating efficiency. Another element that is part of the project is the sludge dewatering beds. Along with the sand filters, the drying beds need to be sized to be able to hold the required capacity and contain the necessary amounts of materials to perform as desired. The final component as part of the treatment system is the ultra-violet (UV) disinfection. The UV system must be capable of providing enough disinfection for the determined flow and treat to reach the required treated

effluent standard. All these main components are part of the project design tasks for this project. Each task requires in-depth research and/or calculation in order to allow the entire system to function properly.

DESIGN CRITERIA

Environmental Discharge Standards

Because of the environmental focus of the project, it was imperative to identify the most suitable environmental discharge standards for the wastewater system to adhere to. To this effect, the design team used the United Nations Environmental Programme standards for coral reef discharge regulations. These were the most appropriate standards the design team determined for wastewater discharge into the reef waters surrounding Pulau Siladen. Specific standards are presented below in Table 1. The project is designed to adhere to the more stringent Class 1 Water standards.

Parameter	Class 1 Waters	Class 2 Waters
Total Suspended Solids	30 mg/l	150 mg/l
Biochemical Oxygen Demand (BOD₅)	30 mg/l	150 mg/l
pH	5-10 pH units	5-10 pH units
Fats, Oil and Grease	15 mg/l	50 mg/l
Faecal Coliform or	Faecal coliform: 200 mpn/100ml	
E. coli.or	E. coli: 126 organisms/100ml	Not applicable
Entrerococci	Entrerococci: 35 org./100ml	
Floatables	Not visible	Not visible

Table 1: UNEP Standards for Discharge into Coral Reef Ocean Waters (UNEP).

The primary criteria of critical importance for reef discharge standards is the requirements for total suspended solids (TSS) and biological oxygen demand (BOD₅) levels.

Class 1 standards mandate that average monthly values of TSS and BOD levels must not exceed 30 mg/L. This is also known as the 30-30 rule.

Determination of Average Daily Flow

Average daily flow of wastewater generated is the primary criteria in sizing any WWT system. In order to size and design the sump, the peak flow must also be known, which is determined using the average daily flow. The approach chosen to find the average daily flow took into account all the sources of wastewater on the island from which wastewater would enter the collection system. Sources such as sinks, toilets, and showers were among the list. The island contact provided a best guess estimate of the amount of each different source of wastewater would be on the whole island. Next, the amount of wastewater flow from each source was researched and altered by estimation. There are currently about 350 people residing on the island. Most are locals while the rest are tourists. In order to allow for generous population growth on the island (double that of contact's population growth estimate), the system was designed to serve 450 people - 300 locals and 150 guests. The wastewater produced from each source was measured in gallons per person per day. This number was multiplied by the number of people using each source. All these factors were added together to equal the total amount of average flow per day, which was calculated to be 19,650 gallons per day. 20,000 gallons per day was used instead for the daily flow to be treated. This is equivalent to a flow of 13.9 gallons per minute of waste entering the system to be treated. The calculations for the determination of average daily flow are shown below in Table 2.

Source	Amount Per Person Per Day (gallons)	Number of People	Gallons
Sink	10	450	4500
Shower	25	150	3750
Toilet	9	450	4050
Laundry Machine (35 gallons per wash, only wash once a week)	5	150	750
Laundry by Hand (about 20 gallons per week)	3	300	900
Bucket Showers	4	300	1200
Dishwashing by Hand	10	450	4500
Total Gallons per Day:			19650

Table 2: Determination of Average Daily Flow.

SYSTEM COMPONENTS AND DESIGN

Sewer Network Design

With the essential data of expected average daily flow known, the first step is to design an adequately sized collection system, fed by gravity to convey wastewater from source locations to the centralized treatment system. Since the calculated 20,000 gallons per day is only an average, it gives no information as to how much flow will be experienced at one moment, as wastewater will not be generated at a constant rate throughout the day. Using the Babbitt equation, which considers the island's population, the peaking factor was determined to be 5 – the highest value that can be applied in the modeling program 'SewerCAD V8i' which was used to design the sewer network. Using this peaking factor, the peak hourly flow was determined to be 4200 gallons, all data was inputted in the SewerCAD program. This program is a powerful tool that calculates using the Manning's equation, the most appropriate pipe and manhole characteristics and profiles, mainly slope and pipe diameter requirements. To determine the required slopes and other criteria, ground elevations and other geographic constraints must be inputted into the model, to satisfy the required range of 3ft-10ft of pipe cover and full gravity flow be achieved. Because this is will be a newly constructed sewer network, Infiltration and Inflow are neglected. After extensive searching, the design team found that no topographic data is available for Pulau Siladen, so the design team utilized the geographic data afforded by Google Earth. Using the built-in Google Earth functionality in Civil3D 2011, the design team was able to import the 3D map provided by Google Earth and set it correct to a standardized Indonesian Datum and accurate real-world coordinates as seen in Appendix N. A three-dimensional topographic map was generated with island photo overlay, and since the model is set to the datum, Civil3D was able to provide elevations relative to sea-level at any location on

the 3D model. A screen capture of the topographic model used for overall system design as well as ground elevations for SewerCAD is displayed below in Figure 18, where the thick green line represents the proposed sewer line installation, under the road, to collect all sources of wastewater.

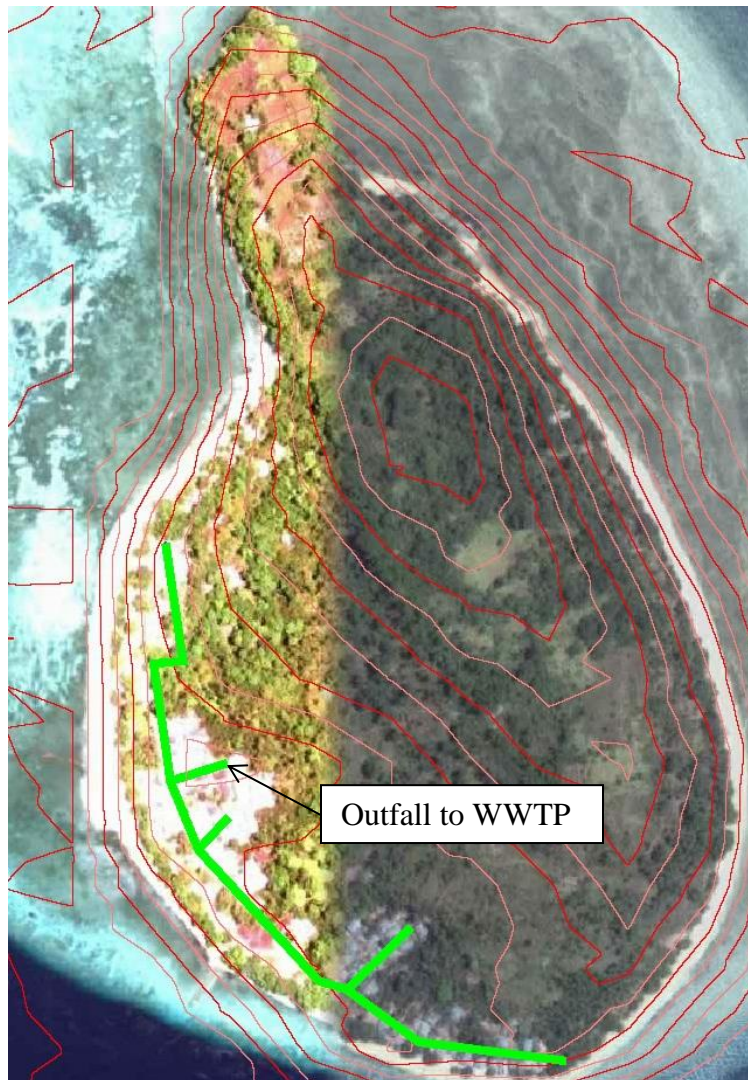


Figure 18: Screen capture of generated 3D model.

Using the elevation and geographic data afforded by the 3D model, a system schematic shown in Figure 19, was generated in SewerCAD, and sufficient data was known for the program to generate a design. Data for each manhole specifying how much waste each manhole will serve, was part of the main criteria in determining the specific amounts of flow that are

occurring through each pipe in the system, generating component characteristic tables, included in Appendix A.

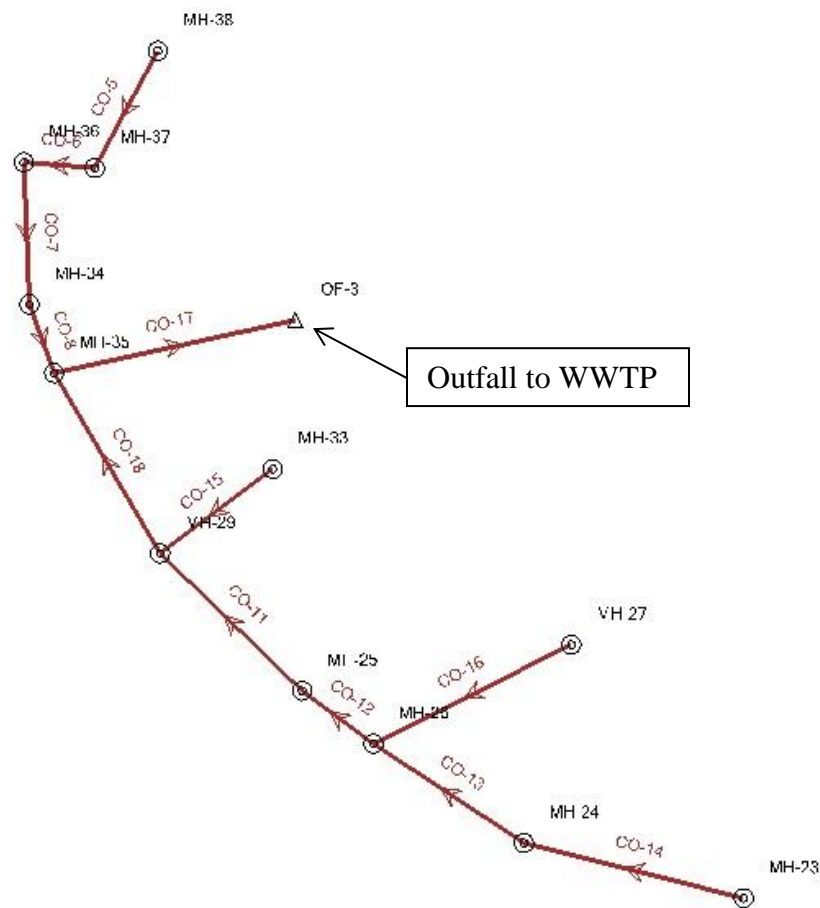


Figure 19: Sewer system design schematic.

After many failed network calculations, and tweaking variables, the SewerCAD model finally displayed no error messages, which indicated that the program was successful in designing a fully gravity-fed sewer system, meeting required ranges for flow velocity, pipe slope and cover etc. The conduit characteristic tables in Appendix A, show that extremely low flow is experienced through the northernmost conduit, meaning that the required minimum flow velocity of 1ft/s is not satisfied. As a solution, the design team determined that a clean-out valve would be installed as part of the northernmost manhole, so that flushing may occur, preventing residual solid buildup in the sewers.

SewerCAD was able to generate pipe profiles with reference to land elevations, depicted below in Figure 20.

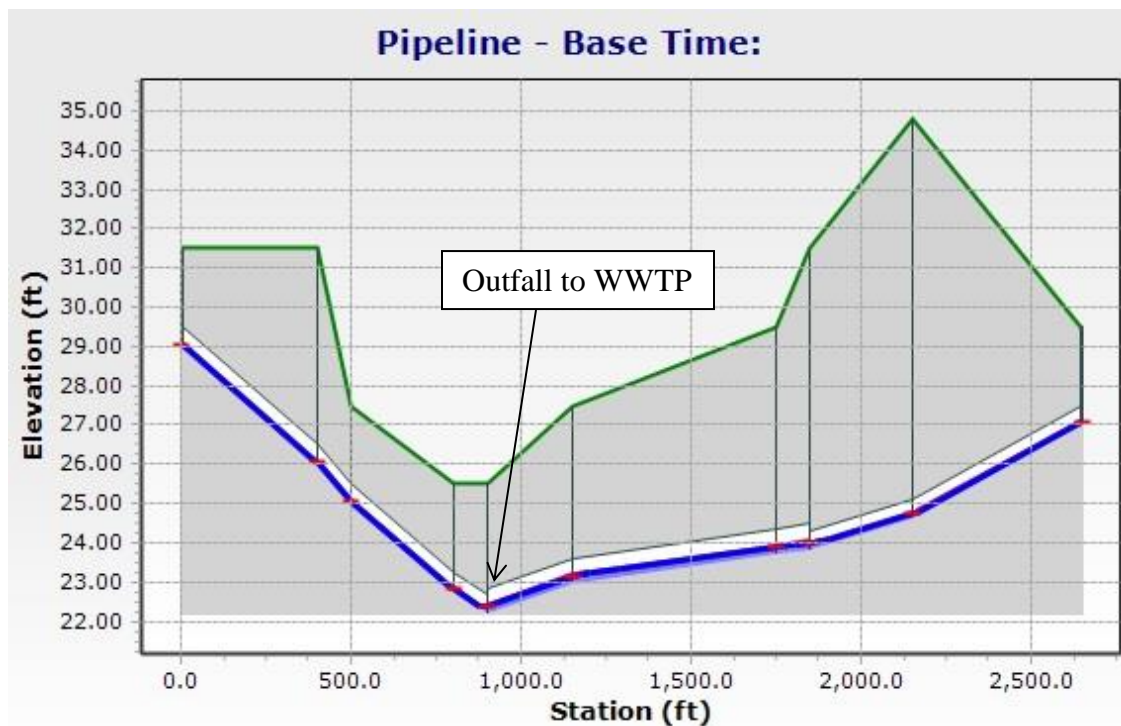


Figure 20: Main pipeline profile, 0 Station represents the system's northernmost point.

The outfall point depicted in the above images, coincides with a depression in elevation which is the lowest point in the entire sewer network. After discussion with the island contact, a site location was selected, described in further sections.

It was determined that the sewer network will be composed of 6" and 8" diameter PVC pipes. Further pipe information is displayed in the conduit tables in Appendix A. PVC was identified as the ideal pipe material as it is light, cheap and durable enough for the application at hand, where concrete or iron piping would be too heavy duty to deliver and construct on Pulau Siladen. Standard details are provided in Appendix B, that specify pipe and manhole construction drawings, adapted from the city of San Jose's published typical details.

Flow Equalization Sump

There exists a large amount of variation in wastewater flow through the sewers at different times of the day. In general, the “amount of variation tends to increase with a decrease in sewer system size, because of the lack of damping effects from longer flow times found in larger systems... The extreme low flow usually occurs between 2am and 6am, with two peaks occurring during daylight hours around 9am and 6pm.” (Wastewater Treatment - EPA) Because of the highly varying nature of flow to be expected, the design team wished to equalize the influent prior to discharge into the SBR for treatment.

The flow trend depicted in Figure 21 represents the variation in flow of a similar small, sewerred residential community. The design team adapted its assumed flow trends from this diagram and applied the trend ratios to the average daily flow. The excel calculations can be found in Appendix C, where the cumulative difference in outflow into the sump and SBR was calculated, assuming a sump pumping rate of the 13.9 GPM value stated earlier. This allowed for a calculation of the High water level (HWL) and Low water level (LWL), in determining the difference in these values which represents the equalization volume of water required by the sump of 5125 gallons.

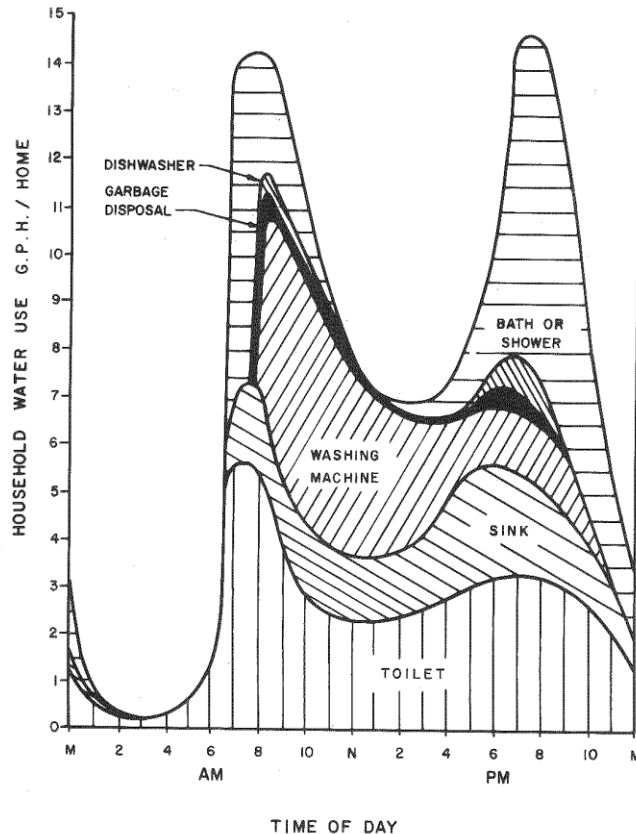


FIGURE 2-4

DAILY HOUSEHOLD WATER USE (25)

Figure 21: Daily flow trend.

The equalization sump is required to be situated at the location of the sewer outfall, and adjacent to the SBR. Because the sewer outfall is located 3ft below grade, it was determined that a cylindrical concrete basin below grade was the most effective design of the sump. The tank has an inner diameter of 14ft, with 1ft thick concrete walls. This tank will protrude up from the ground for accessibility, and sinks 12ft below grade. It would need to accommodate the 5125 gallon difference in LWL and HWL, while also keeping a wet-well below the LWL for a fully submerged sump pump, accessible for maintenance by manhole and ladder. The design drawing is displayed below in Figure 22 with detailed drawing in Appendix D.

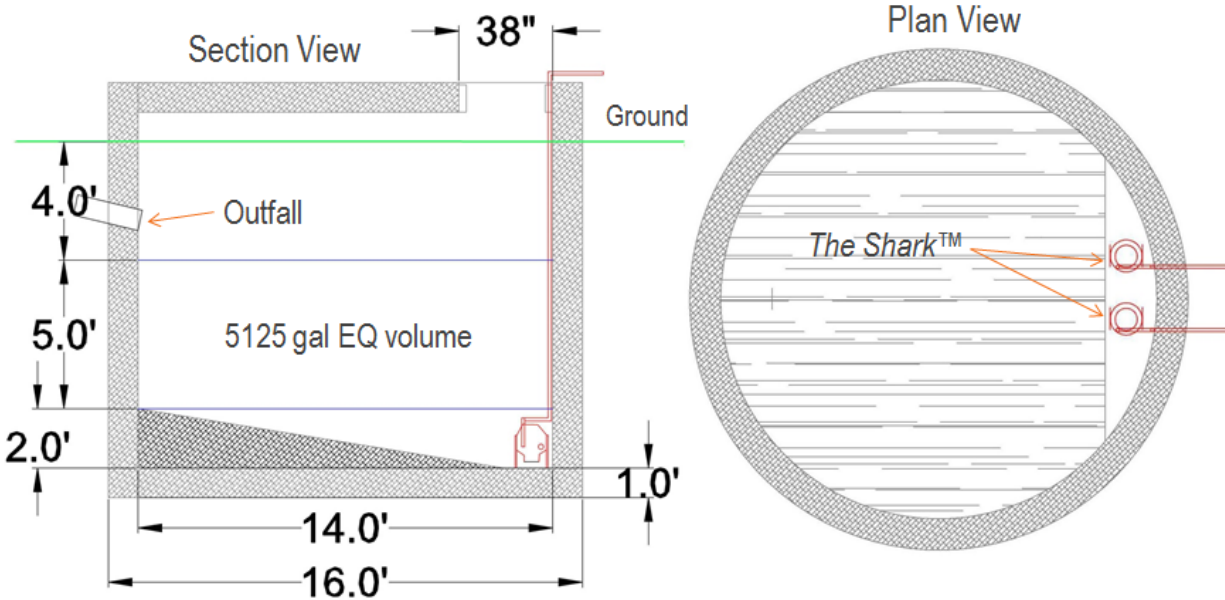


Figure 22: Sump Section and Plan view.

The sump will feature a sloped bottom so that all solids are collected by the grinder pumps. Grinder pumps were selected as the sump pumps because screening is not being provided, as it is assumed that solids other than excrement will not end up in the collection system. 2 grinder pumps are designed to be fixed to the bottom of the basin, 1 pump for regular operation and the other as a redundant part in case of failure. These pumps are operated by float switches, and the outlets are fitted with 1 1/4" NPT galvanized steel piping, that rises above grade to the SBR. With elevations of the sump and SBR determined, the design team determined that 15ft of static lift is required, and using the Darcy-Weisbach equation and summing minor losses, head loss was calculated to be 3ft, determining the required pumping head to be 18ft. As stated earlier, 13.9 GPM is required for the average daily flow to be accommodated by the sump and SBR system, so a conservative 16 GPM flow rate was specified for the required pump flow. Upon reviewing many models of grinder pumps, the Zoeller model 915 – *The Shark* was selected as the most appropriate pump and at a reasonable price of \$1,426 per unit. (Grainger)

Study of the manufacturer's published specifications and pump performance curve depicted in Figure 23, show that the required pumping head and flow rate lies in the most efficient range to pump at, meaning that this pump is the perfect selection for the specified criteria, minimizing pumping energy requirements.

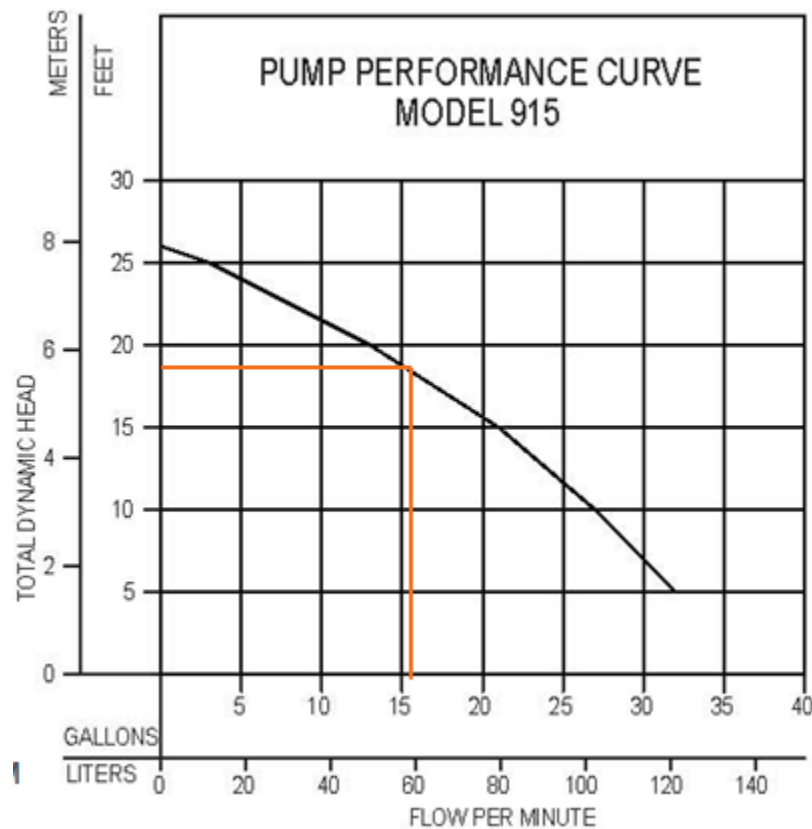


Figure 23: Pump performance curve for Model 915. Operating in efficient region.

Treatment System Components

All wastewater from the entire island is collected by the sewer system and transported to the location of the treatment system. The actual treatment system is composed of several parts. The water flows from the sewer into the equalization basin, or sump. The sump collects and equalizes the flow throughout each day so that there is a constant flow into the sequencing batch reactor. The sequencing batch reactor (SBR) is an activated sludge process designed to provide biological treatment in the multiple phases mentioned earlier. The SBR is mainly responsible for removal of the biological oxygen demand (BOD₅) and the total suspended solids (TSS). After a cycle of SBR treatment, the wastewater is decanted into the slow trickle sand filters. These provide further filtration of the wastewater. Once the wastewater has traveled through the sand filters, it is conveyed to the UV disinfection system. The UV system disinfects the wastewater so that it can be safely discharged into the ocean without fear of exposing swimmers to harmful pathogens. There is a possible site and system for future chlorination so that some wastewater may be used towards water reclamation.

In the SBR system, sludge is actively retained in order to biologically treat the wastewater. However, some of that sludge is removed each day in order to maintain a steady state in the reactor. The sludge that is removed is manually transported in 55 gallon drums to the sludge drying or dewatering bed. This drying bed allows the sludge to dry so that it can be used for land application, as it is a natural fertilizer.

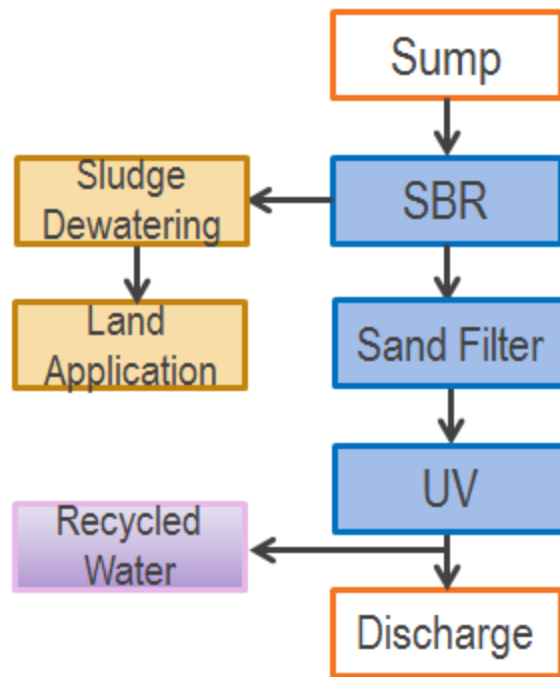


Figure 24: Conceptual flowchart of treatment process.

A detailed drawing of the proposed overall layout of the system can be seen below in Figure26, with full size drawing in Appendix E. The flow in and out of the system is indicated by the arrows. The entire system covers an approximate 70 ft by 100 ft area. There is a 100 ft by 100 ft parcel of land photographed by the contact in Figure 25, that is currently used as solid trash storage which is located at the outfall of the sewer network. This area is kept out of site and away from guests, which helps the odor emitted by sewage to be less unpleasant for inhabitants.



Figure 25: Proposed site location, at low point of sewer network.

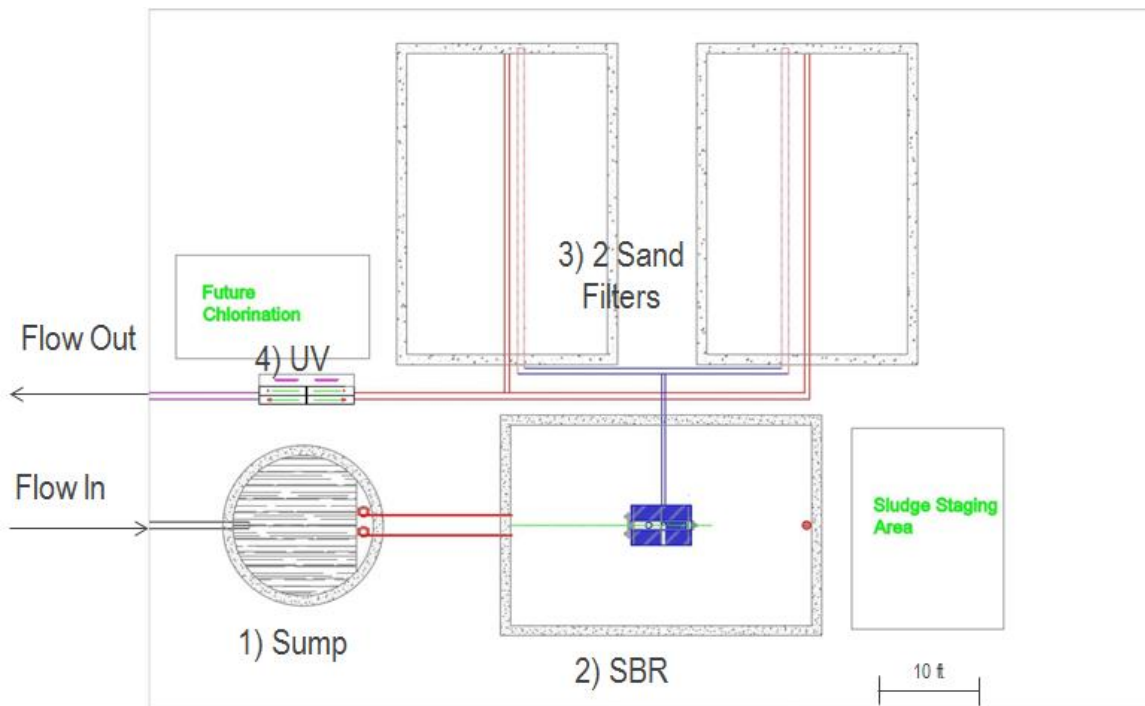


Figure 26: Proposed system layout.

Sequencing Batch Reactor

As mentioned, the Sequencing Batch Reactor (SBR) is the chosen method of treatment for this project. It uses an activated sludge process to biologically treat wastewater. The process removes BOD₅ and TSS while providing nitrification and denitrification. The system operates in multiple phases: filling, anoxic mixing, aerobic mixing, settling, and decant.

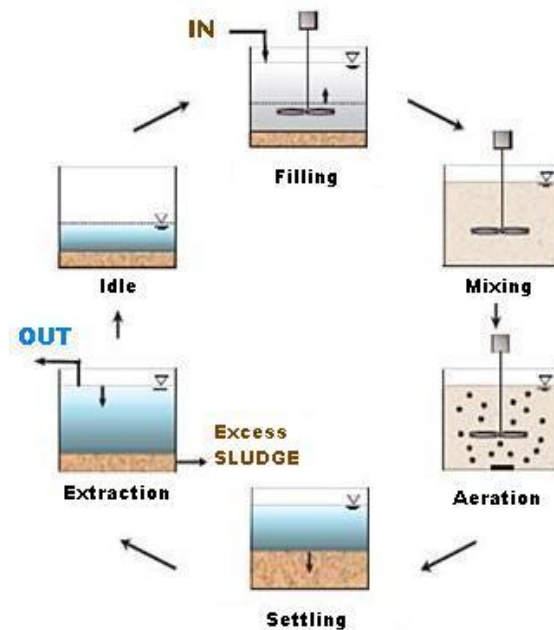


Figure 27: Flowchart illustrating each SBR phase.

These phases operate on a continuous cycle. In the anoxic phase, influent wastewater is mixed with the sludge to provide contact between microorganisms and the substrate. This mixing creates an environment that is favorable for the procreation of microorganisms, and the Anoxic conditions provide nitrogen removal. The aerobic phase provides oxygen so that the microorganisms can feed on the substrate. Adjusting the timing of these phases can provide a simple way to create an environment where nitrification and denitrification occur. The goal is to have the microorganisms to completely remove all TSS, BOD₅ and adequate nitrogen removal. The amount of removal depends on the length of the phases. The settling phase is when the aeration and mixing cease to allow separation of solids. The sludge sinks to the bottom leaving

treated effluent above. The decant phase removes the treated effluent from the tank lowering the water level to a designated Low water level. Some of the sludge is then pumped out and transported to the dewatering bed. Sludge will be wasted through the use of a designated sludge pump with flexible hose to fill the barrels. The Allegro model 9404-04 submersible sludge pump, was selected for its relatively low but sufficient pumping head and power requirements. This model is by far the most cost effective unit after research of potential other products. 2 pumps will be purchased initially, at \$716 per unit. One unit will be fixed in the SBR and the other held on site as a spare. Manufacturer spec sheet is included in Appendix F. After decant phase completion, the daily cycle starts over.

During the design process, various methods of constructing the SBR were considered. The most simple design is a square or rectangular base with surrounding walls and an open top. A circular tank was also considered but ruled out due to difficulty in construction. A third option was an earthen basin lined with *BIOWORKS* lining, a heavy duty, high density polyurethane lining designed for earthen basins containing sewage. (BIOWORKS) This was the cheapest option considering materials costs. However, the required footprint it would cover to hold enough wastewater while maintaining a suitable slope for earth basin stability, far exceeded the available space, ruling this option out. The most suitable choice for this project is a concrete rectangular basin. Table 3 displays the potential dimensions calculated for sufficient basin size.

Rectangular Design					Volume Required	
L (ft)	W (ft)	H (ft)	Volume (ft ³)	Volume (gal)	ft ³	Gallons
20	20	14	5600	41891	5350	40000
25	25	9	5625	42078	5350	40000
30	30	6	5400	40395	5350	40000
18	18	17	5508	41203	5350	40000
20	30	9	5400	40395	5350	40000

Table 3: Possible Tank Sizes for the SBR

The SBR in this project is specifically designed to meet the island's needs. It is a concrete tank with a maximum capacity of 40,000 gallons. The inner dimensions are 20 feet by 30 feet by 9 feet high, with added 2 ft for freeboard, making the tank a 20x30x11 ft basin. The walls are 1ft thick. The tank is partially below grade, with five feet above ground. The reason for the design of 40,000 gallons is because 20,000 gallons are actively retained while 20,000 gallons are decanted daily. However, there is the possibility of having a maximum of 40,000 gallons in the tank at one time. The AquaCAM-D unit from *Aqua Aerobics* is incorporated in the SBR to provide the aerobic, anoxic, and decant phases. This unit is explained further in following sections. A design drawings with plan view and section view of the SBR can be seen in Appendix G.



Figure 28: Similar concrete basin with AquaCAM-D unit.

Sequencing Batch Reactor Design Criteria

Design criteria for the sequencing batch reactor were based off the flow rate entering the system and standard design values for extended aeration systems (UNEP). As determined previously, the system is designed for an influent flow rate of 20,000 gallons/day. The system is estimated to have an influent BOD concentration of 300 mg/L. This was determined using an average American BOD value of 220 mg/L² and adjusting it to reflect the more concentrated sources of waste on the island due to lack of industrial effluent. Extended-aeration systems typically remove 85-95% of the influent BOD levels making the effluent BOD range between 15-30 mg/L, adhering to UNEP standards. The design sludge age is approximately 30 days because the lower flow rate allows the sludge to sit for a longer period of time. The mixed liquor suspended solids (MLSS) design range is between 3,500-4,500 mg/L, a more concentrated range than the typical 3,000-6,000 mg/L for extended aeration systems¹.

Design Flow Rate (gal/day)	Influent BOD (mg/L)	Effluent BOD (mg/L)	Sludge Age (days)	MLSS range (mg/L)
20000	300	15-30	30+	3500-4500

Table 4: Design Criteria for the Sequencing Batch Reactor System

AquaCAM-D

Discussed earlier were the design team's considerations for the equipment that will provide the mixing, aeration and decant necessary for a SBR to function. Many potential solutions were discussed, such as design perforated pipes with air pumps, separate mixers and a custom designed decant method. Providing the hardware in this manner would help reduce the cost of implementation as the parts would be made from simple readily-available parts. However since the requirement of minimal process control is part of the design team's main goals, it was determined that an all in one system, designed by professionals was the most appropriate solution, as installation, maintenance and diagnostics can be assisted by a company specializing in said parts. The AquaCAM-D unit was selected because it is "a performance proven aerator/mixer/decanter designed for use in Sequencing Batch Reactor (SBR) systems treating flows as low as a few thousand gallons per day up to 100,000 gallons per day. The unit is used successfully in a variety of municipal and industrial applications for both pretreatment and secondary wastewater treatment. The AquaCAM-D effectively and independently aerates and mixes the SBR reactor while offering subsurface decanting of final effluent." (Aqua-Aerobics)

This unit will be installed by floating on the top of the water level, restricted by simple guide rails that allow the unit to decant in a simple manner. This unit has many features and added options that allow it to be an intelligent and autonomous system, such as a computer display with relevant data and ergonomic operation. Optional Dissolved Oxygen sensors with added equipment can allow the system to alter its own phase timing schedule to make the treatment process more efficient. Furthermore Ethernet network functionality can be added, that allows this unit to be monitored and operated remotely.

The design team submitted a design request form to Aqua-Aerobics, with detailed custom design criteria determined by the team. Project Application Engineer Rungrod Jittawattanasat, Ph.D. produced a design report included in Appendix H for the CAM-D unit custom for the project's design specifications. For the particular characteristics of Siladen's SBR system, a 10hp motor unit to provide mixing, aeration and decant pumping was suggested. The "Preliminary price for equipment listed on the design including freight and standard supervision service is \$192,700." – Jittawattanasat

Initially the calculated cost of \$193,000 was staggering and much higher than expected. However a premium is always to be paid for a high tech, all-in-one unit with manufacturing support and guarantee. Most of the options were selected so as to ensure a more autonomous operation of the unit, however options can be removed depending on budget requirements if sacrifices to the intelligence of the system are to be accepted.

Tentative SBR Daily Timing Schedule

While the AquaCAM-D unit may intelligently alter its phase timing schedule, the design team developed a tentative SBR daily timing schedule, so that 1 cycle may operate per day to provide required treatment. Utilizing the same daily flow trend displayed in Figure 21, the design team considered the high flows experienced during the day, and ~0 flow during the 2am-6am period. Throughout the day the SBR would be constantly filling and mixing, accounting for the mix and aeration phases identified as part of the SBR cycle. The settle and decant phases rely on 0 flow entering the reactor so that all particle may settle adequately, thus it was decided to capitalize on the extreme low flow during early morning hours to accommodate the settle and decant phases. Apart from the settle and decant phases, the Table 5, below shows that mixing status is constantly on. Aeration status will be alternated to create and aerobic and anoxic conditions vital in ensuring proper BOD removal as well as additional denitrification.

A report titled *Nitrogen removal in a low-loaded single tank sequencing batch reactor*, by John Palis and Robert Irvine describe the testing set-up and results due to varying aerobic and anoxic conditions using differing phase timing. The report concludes that by simply ceasing aeration once adequate nitrification has occurred, the anoxic conditions produced result in impressive denitrification and increased Ph stability. (Palis & Irvine)

This timing schedule is tentative, and the only way to meaningfully improve the schedule would be to monitor various chemical concentrations during actual running of the system specific to Siladen's SBR. Instead, with the added intelligent options and DO sensor of the AquaCAM-D unit, the timing schedule can be improved most effectively but the unit autonomously.

Hour	Mix Status	Aeration Status	Growth Environment	Hour	Mix Status	Aeration Status	Growth Environment
6am	On	On	Aerobic	6pm	On	On	Aerobic
7am	On	Off	Anoxic	7pm	On	Off	Anoxic
8am	On	On	Aerobic	8pm	On	On	Aerobic
9am	On	Off	Anoxic	9pm	On	Off	Anoxic
10am	On	On	Aerobic	10pm	On	On	Aerobic
11am	On	Off	Anoxic	11pm	On	Off	Anoxic
12pm	On	On	Aerobic	12am	On	On	Aerobic
1pm	On	Off	Anoxic	1am	On	Off	Anoxic
2pm	On	On	Aerobic	2am	Settle	Off	N/A
3pm	On	Off	Anoxic	3am	Settle	Off	N/A
4pm	On	On	Aerobic	4am	Decant	Off	N/A
5pm	On	Off	Anoxic	5am	Decant	Off	N/A

Table 5: Tentative daily timing schedule.

Slow Trickle Sand Filters

The decanted water from the SBR is pumped into the slow trickle sand filters. There are two sand filters in this system, however only one will be in use at a time. The other is for redundancy or maintenance issues, such as cleaning. The tanks are designed with the same dimensions as the SBR tank, except a slight 1:20 ratio slope on the floor leading to the center for the water to drain. The tank is designed to hold a maximum capacity of 20,000 gallons of wastewater at one time along with the filtration materials. There are two and half feet of sand and two and a half feet of gravel that provide the filtration. The sand and gravel occupy a significant amount of volume in the tank. Below is a table that shows the sizing options for the sand filters. The chosen solution was the same as the SBR because it has enough capacity to hold enough sand and gravel as well as the 20,000 gallons of wastewater.

Rectangular Design					Volume Required	
L (ft)	W (ft)	H (ft)	Volume (ft ³)	Volume (gal)	ft ³	gallons
20	12	17	4080	30521	3275	20000
30	10	15	4500	33662	3425	20000
30	15	9	4050	30296	3800	20000
20	30	9	5400	40395	4175	20000

Table 6: Possible Tank Sizes for the Sand Filters

The influent and effluent pipes are perforated PVC pipes. This allows the wastewater to exit the influent pipe and enter the effluent pipe beneath the filtration materials. A section view and plan view of the sand filters can be seen in Appendix I.

Sludge Drying Bed

The purpose of the sludge drying bed is to allow the sludge to be dewatered by the sun before it is used for land application. Water in the sludge permeates through layers of sand and gravel and then exits the beds to be put back into the treatment system. This is an environmentally mindful approach to handling sludge removal, as it requires no power and few, simple parts compared to other possible solutions like belt or centrifuge dewatering.

The beds are located at an offsite location away from the other treatment system components. There are eight modules in the drying bed, with each module holding one day's generated sludge. The system is designed for a seven day drying cycle. So, seven of the modules would always be in use, emptying out the oldest sludge in a module and replacing it with new sludge. The eighth is a redundant module so that any necessary cleaning or maintenance can be performed without disrupting the seven day cycle. From the calculations included in Appendix J, there is approximately 250 gallons of sludge per day being removed from the SBR. Each module was sized according to this value. Each module is five feet by seven feet and almost 4 feet deep. The entire bed is 17 feet by 25 feet and just over 6 feet high. There are four layers of sand or gravel. The top layer is one half foot of fine sand. The next layer is one quarter foot of coarse sand. Then, there is one quarter foot of fine gravel. The bottom layer is one quarter foot of coarse gravel. A plan view and section view can be seen in Appendix K.

Disinfection

During the design process, the project team devised two possible solutions for providing adequate disinfection to treat the water to a higher quality, safe for swimmers and divers.

Chlorination

Because it is widely used for wastewater treatment systems, chlorination was considered an option for disinfection. It can also be supplied in various different ways, making it a versatile treatment option. Unfortunately, the disadvantages associated with water chlorination do not make it the best option for Pulau Siladen. Three in particular are especially harmful for Pulau Siladen: chlorine residual is toxic to aquatic life, chlorine's toxicity would require special handling, and potential long-term environmental effects (United States Environmental Protection Agency, 1999). Each of these disadvantages might compromise the goal of improving the area's environmental health, so chlorination was not chosen for disinfection.

Ultraviolet Radiation

Ultraviolet Radiation has two key advantages that make it the most preferable solution for Pulau Siladen. First, there is no residual environmental effect after disinfection (United States Environmental Protection Agency, 2003). This is important because of the coral reefs that surround the island. UV systems also require less space and no storage of chemicals, than other disinfection systems (United States Environmental Protection Agency, 2003). Because of the limited space on Pulau Siladen, it is ideal to conserve space whenever possible. Between chlorination and UV radiation, UV radiation is a better solution for wastewater treatment on Pulau Siladen.

The UV disinfection system is based off the Tipton Environmental TEII-600-AZ model. Technical information can be found in Appendix L. The unit itself, according to Tipton's

website, is designed to treat a flow of 52 gallons per minute (Tipton Environmental Inc.). The system will have six 36" lamps and water has a 65% transmittance rate (Alberta Water and Wastewater Operators Association). The wastewater will enter the UV system through an 8" pipe. It will pass through the treatment system, which is approximately 8 feet long, and exit through a similar 8" pipe. The power supply will be mounted on a 5-foot high wall, where power cords will connect to the top of the system. A conceptual drawing of the UV system can be found in Appendix M.



Figure 29: Tipton TEII model as delivered to client. (Tipton Environmental Inc.)

ENGINEER'S OPINION OF MOST PROBABLE COST

Component	Quantity	Unit	Cost/Quantity	Total Cost (USD)
Pipe	3300	Linear Feet	\$12.05	\$33,800
Earthwork	700	Cubic Yards	\$5.42	\$3,800
Concrete	68	Cubic Yards	\$75	\$15,400
Sump Pump	2	Each	\$1,450	\$2,900
Aqua-CAM-D	1	Each	\$193,000	\$193,000
Sludge Pump	2	Each	\$750	\$1,500
UV System	1	Each	\$7,700	\$7,700
Labor	N/A	N/A	\$10,000	\$10,000
Engineering + Contingency	N/A	N/A	\$14,400	\$14,400
TOTAL				\$282,500

Table 7: Breakdown of probable project costs.

Piping

Piping is required primarily for the sewer system, which needs 3300 linear feet of pipe. 8" PVC pipe costs approximately \$12.05/foot (U.S. Plastic Corporation). Multiplying that out, the piping will cost about **\$33,800**.

Excavation

700 cubic yards of excavation would be necessary for installing the sewer system and the sequencing batch reactor. Using a rate of \$5.42/yd³ (Washington State Department of Transportation), excavation is estimated to cost about **\$3,800**.

Concrete

The bulk of the concrete will be used to build the concrete basin, which requires 68 yd³ of concrete. Concrete will cost approximately \$75/yd³ (Concrete Network). Therefore, concrete will cost about **\$15,400**.

Pumps

Both sump pumps and sludge pumps are ordered as entire units. The project team received quotes for pumps and determined the probable cost based on those quotes. Because of redundancy, two of each pump would be ordered. Respectively, the sump pumps will cost **\$2,900** while the sludge pumps will cost **\$1,500**.

AquaCAM-D

The AQUA-CAM-D is the primary component of the sequencing batch reactor and the most expensive piece of equipment. Based on a quote from Rungrod Jittawattanasat, Ph.D., the AQUA-CAM-D will cost approximately **\$193,000**.

Labor and Contingency

While highly variable, it is imperative to set aside money for labor and contingency purposes. Labor costs are all-inclusive and take into account the lower labor rates in Indonesia. That being said, **\$10,000** is being set aside from labor. To ensure that there are enough funds to compensate for issues that appear in the field, **\$14,400**, (about 8% of the system cost) is being set aside for engineering and contingency costs.

OTHER ISSUES

Non-Technical Issues

The project has four non-technical issues that need to be addressed as it moves forward. The first one would be handling foreign regulations. While the project has been designed using a number of assumptions in America, construction and implementation of the system would be subject to Indonesian laws. It would be imperative going forward to perform extensive research on Indonesian laws and how they will impact development of the wastewater system. The level of Indonesian government support and oversight is another non-technical issue associated with the project. Indonesia currently has widespread sanitation problems within the country. Management of water sanitation is influenced by government policy at both state and local levels but currently the roles of government are unclear in water sanitation issues. Having the government place a greater amount of emphasis on wastewater sanitation would be a boon to the development of the project. Community support of the project is the third non-technical issue associated with the project. In terms of infrastructure, the project would have a huge impact on the island. Installation of the sewer network would require removal of the road on the island and a whole new wastewater system would be installed. The project is ultimately to improve the well-being of Pulau Siladen's community but it would not fulfill its purpose without the support of the community itself. Finally, determining payment for the project is an underlying issue. Who would be responsible for paying for the project: residents of the island, resort owners, or the Indonesian government? There would need to be some sort of resolution regarding payment of the project before it can move forward.

Ethical Issues

Along with non-technical issues, the project has some ethical issues associated with it. The first is the acquisition of property for the project. Relatively speaking, the project requires a large amount of land, most of which is currently owned privately. Ethical concerns would arise with how to acquire that property. Could a fair negotiation for the land be conducted or would the implementation of eminent domain be required? Environmental impacts associated with construction of the system pose another ethical issue. Despite the environmental focus of the project, would it be ethical if the construction damages the environment? It is imperative that the project construction leaves the environment in as good if not better condition than before the construction started. Similar to environmental impacts, maintaining adequate public health is an ethical issue. It needs to be certain that the project will improve the well-being of both the environment and population before it can proceed. Finally, labor conditions for the project presents a huge ethical issue. As explained earlier, the minimum wage in Indonesia lags greatly behind the minimum wage in America. Work in Indonesia is highly susceptible to be exploited for cheap labor. Ethically speaking, it is important that workers on the project are paid a living wage and are not exploited.

Conclusion

The goal of designing a low-impact wastewater treatment system for Siladen Island was to develop a system that would treat wastewater in order to both preserve the surrounding environment and improve sanitation on the island. The main focus of this project was to create a design that could sufficiently treat wastewater before discharge into the ocean. As a result, the coral reefs could be preserved and the drinking water supply would not be at risk. The design team focused on ensuring the system is feasible for a small population while providing an acceptable amount of treatment to do that. The team was in communication with a resort owner on the island to ensure accurate design conditions, both regarding population and geography, for the system. A collection system was designed to ensure that contaminated wastewater reaches the treatment system in a controlled manner. The wastewater then undergoes treatment within the sequencing batch reactor and is subsequently treated using ultraviolet radiation. After UV radiation, the treated water is discharged into the ocean. Overall, the system will provide sewage treatment with the potential for recycled water production in the future.

Considering this project was conceived from scratch, the wastewater treatment design is still in a fairly conceptual stage. The current design proves that it is feasible to design a wastewater treatment system for small islands like Pulau Siladen. The team recommends that other design teams take the current wastewater system design and expand upon it. One of the tertiary goals of the project heading in was to design a system that is compatible on islands similar to Pulau Siladen. A focus on creating a more refined, adaptable solution from using this current design would be ideal.

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